Event Monitoring

Ground-Based Visual Observation Studies for the Comprehensive Test Ban Treaty (CTBT)

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Although the U.S. Senate did not ratify the CTBT in 1999, as a signatory the U.S. still has considerable responsibility to implement it, and we are working with LLNL, SNL, and other U.S. agencies (primarily DoD and the Department of State) on this effort. On-site inspection (OSI), which includes visual observation, seismic aftershock monitoring, and radionuclide sampling, as well as other geophysical techniques (even drilling), is a critical part of treaty verification. Los Alamos is the lead organization in the area of ground-based visual observation.

We wrote the section on visual observation techniques for the OSI Operational Manual, in addition to writing the entire chapter on Health and Safety and preparing tutorials on geophysical and radiological signatures of underground nuclear explosions. We also participated in OSI table-top exercises with the Russian Federation and workshops with Israel and Kazakhstan, as well as UN-supported multinational workshops sponsored by the CTBT Organization in Vienna, Austria. We have provided numerous equipment specifications and considerable policy guidance for U.S. position papers in these areas.

Los Alamos Knowledge Base for Seismic Monitoring Research in Asia

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Since the signing of the CTBT in 1992, research associated with seismic monitoring in Asia has become increasingly important. To support this research, we have developed and maintain the Seismic-Research Knowledge Base, a Los Alamos database that includes a vast amount of open data. This database provides the mechanism for researchers to obtain the information they need to locate, characterize, and discriminate events (natural or man-made), that produce small-magnitude seismic signals recorded at regional distances (200 to 2,000 km). For example, using this database, other EES researchers have developed magnitude and distance amplitude correction parameters for observing events from the Lop Nor region in China, aiding in creation of travel-time tables, velocity models, and 2-D propagation path corrections for regional *P* phases from this region.

The information in our database is also currently being incorporated into a new database of regional magnitude scales, which is based on single-station $m_b(L_g)$ measurements. Researches have also used our database to create crustal-velocity models and group-velocity curves for specific source-station paths.

The Los Alamos Seismic-Research Knowledge Base is the foundation of the DOE Knowledge Base (KB), a set of databases and various research products that add significantly to U.S. nuclear explosion monitoring capabilities. We work extensively with peers at other national laboratories to ensure that each product being delivered to DOE's KB meets all of our monitoring standards.

Regional Characterization

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Regional characterization is the cornerstone data-collection and analysis function for gathering information needed to detect, locate, identify, and characterize seismic events of concern. This function can be broken into three major components: (1) data collection, (2) regional phase propagation, and (3) quantification of seismicity. The information we collect and process is passed on to specialists on our team, who then organize it and incorporate it into the Los Alamos Seismic-Research Knowledge Base (see above), which is forwarded to the DOE Knowledge Base and used by other U.S. organizations with treaty monitoring responsibilities.

Data collection. The raw materials of our regionalization efforts are seismic waveforms, seismicity catalogues, and station calibration data; we collect data in all three areas at Los Alamos. The most valued waveforms are those from the high-dynamic range, wide-frequency-band recording systems for stable seismographic installations. Seismicity catalogues are collected from data centers producing global and regional event compilations, and they are maintained in databases for use by our researchers. We also obtain independent confirmation of event locations, origins, and sizes to develop ground-truth databases.

Regional wave propagation. The Earth's structure can have profound effects on the character of regional seismograms and on the variability of its character from one propagation path to the next. As a consequence, one must remove propagation effects from regional data in order to be able to identify and characterize the source. To remove propagation effects, we conduct various activities: identifying phases and calibrating travel times, surface wave dispersion, phase attenuation, identifying wave-blockage travel paths, and detection threshold mapping. So far, we have focused on processing single, triaxial sensor data, but we expect to process data from new regional seismic arrays as they are installed and the data is generated.

Quantification of seismicity. Several key factors are important for monitoring a region. These factors include level of seismic activity, event locations, sizes, and event types, both man-made and natural. These data provide essential contextual information for the seismic activity. Seismicity catalogues provide basic information for identifying when and where events occur, so that active fault zones can be identified. Our work refines and improves on the information provided in seismicity catalogues through application of better propagation corrections to regional data.

Experimental Field Studies

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In 1998, 1999, and 2000 we fielded instruments in a multitude of active and passive experiments to support the CTBT and other research in underground facilities and crustal structure. Our unique collection of broadband and short-period accelerometers and velocity meters can record ground motion from 150 g to seismic levels. At the former Soviet test site in Kazakhstan, we monitored a fourth 25-ton, depth-of-burial shot, as well as smaller borehole closure shots at Shagan River. We used the *R*g waves from the hole-closure shots to create tomographic images of the laterally varying seismic velocity at the test site.

The resulting distribution of high and low velocities correlated well with patterns of amplitude residuals from Russian nuclear shots observed at the NORSAR (Norway) array, which enhanced our understanding of how geological structures affect seismic amplitudes observed at great distance. We used amplitude data to estimate explosive yield and monitored the W-1, W-2, and W-3 100-ton tunnel shots at Degelen Mountain. These shots, which were intended to test dynamic stress effects on nearby tunnels, can also be used to calibrate seismic stations that will be used to monitor the CTBT.

Experimental Field Studies

In collaboration with Southern Methodist University, we continued passive monitoring, studying signals from hard-rock mining in the southwest U.S., as well as effects of regional propagation paths on ground motion. This work will help characterize large blasts for purposes of discriminating them from single-shot or nuclear tests. We have also fielded experiments at the Nevada Test Site, in South Korea, and at the MetroWest tunnel near Boston to seismically characterize activity in underground facilities.

Modeling Seismic Sources

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We have an active program in seismic source modeling to help quantify seismic moment (a robust measure of source strength), event depth, and fault orientation. We are also explaining the bias in teleseismic estimates of seismic moment relative to regional estimates, which would lead to biases in calibration of seismic magnitude scales and estimates of seismic yield of explosions. Similar problems have been exceedingly troublesome in the past, and it is important to accurately define the cause, nature and size of region-specific bias of teleseismic moment estimates.

Source depth is a key discriminant of seismic-event type because explosions are much shallower than typical earthquakes, and one can build a reference catalog of typical earthquakes to evaluate future events with respect to faulting depth and orientation. With accurate estimates of seismic-source depth and fault orientation (based on estimates derived from multiple stations at different distances and azimuth from the event), we can then refine the path calibrations that describe the propagation effects from the earthquake to the seismic recording stations. Accurate path calibrations can be used to define path-specific filters to isolate the surface wave portion of the seismogram, which will be useful to study smaller events with weaker signals. This ability to isolate and analyze weak signals from small events will be critical to operational monitoring.

Our work is based on a continuing collaboration with an academic colleague and has substantially extended the capability of our previous work. We initially modeled time domain waveforms for seismic moment tensor estimation. With long and extremely complex regional paths, we found it necessary to model the much simpler amplitude spectra of surface waves at distant stations, as well as the time domain waveforms at closer stations. We hope to improve path characterization so that we can use more time domain waveforms at greater distances than is currently feasible. We are also studying the effects of mantle propagation on the waveforms at the more distant stations and expect to use teleseismic body waves to help constrain depth.

Identifying Regional Seismic Events

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The CTBT bars all “nuclear weapons test explosions and all other nuclear explosions.” On September 24, 1996, the CTBT was opened for signature, and as of October 1999, 155 nations had signed the treaty, including the five original nuclear weapon states. Although the U.S. Senate failed to initially ratify the CTBT, the U.S. will be continuing to improve our national nuclear explosion monitoring capabilities at lower magnitude (yield) thresholds under possibly evasive conditions.

When a nuclear explosion is detonated, it generates signals that can be detected by seismic sensors. The principal elements associated with seismic monitoring for nuclear explosions are signal detection, location, identification, and characterization. In collaboration with LLNL and PNNL, we have been investigating regional seismic event identification methods for the Air Force Technical Applications Center, working on two parallel problems at the same time. First, we are investigating optimal way of deriving regional source and path corrections to derive a set of multivariate normal discriminants and associated errors. Second, we are evaluating different event identification. We have determined that applying corrections to regional phase amplitudes provides

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numerous advantages over preselection of amplitude ratios in terms of performance and operational flexibility.

A fundamental problem associated with event identification lies in deriving corrections that remove path and earthquake source effects on regional phase amplitudes used to construct discriminants. We have derived a set of physically based corrections that are independent of magnitude and distance, and amenable to multivariate discrimination by extending the technique described in Taylor and Hartse (1998). (The complete reference may be found in the Publications Section of this report.) The correction parameters and correction surfaces can be developed offline and entered into an online database for pipeline processing providing multivariate-normal corrected amplitudes for event identification. We developed a multivariate method (regularized discrimination analysis, or RDA) that can be applied to a large number of (possibly correlated) regional seismic discriminants and can be embedded into an elimination of source-type approach (essentially a bank of outlier detectors).

Regional Models and Wave Propagation Path Effects

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We are conducting modeling studies to improve our ability to distinguish between earthquakes and underground conventional or nuclear explosions in other countries. To accurately interpret seismic signals from a possible nuclear proliferator nation, we must have a detailed knowledge of the three-dimensional lithospheric structure between the source and the seismograph. Comparing high-resolution forward models of the seismic signals with models of known sources is another step in defining this structure.

A major part of our effort has been to determine the lithospheric structure of western China. Our simulations of both earthquake and explosion seismic sources help define a Q (measure of seismic wave attenuation) and velocity structure that is fairly refined in two dimensions. We then incorporate these two-dimensional models into a more general three-dimensional description of the lithosphere in western China and nearby India and Pakistan.

We have extended this modeling capability into three dimensions, creating regional models for the Earth's crust and upper mantle that are used for calculating explosion and earthquake travel times and for studying three-dimensional effects on wave propagation across Asia. The models will aid the discrimination and location efforts particularly in areas where there is little a priori knowledge of the geology and seismicity.

Implications of the Shagan River Hole-Closure Shots for Nuclear Explosion Monitoring

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When boreholes at the Russian's Kazakhstan nuclear weapons test site were closed with chemical explosions, we participated in an international study that used those explosions to test and calibrate a prototype system for monitoring nuclear explosions. The event was a unique opportunity to obtain information on the geology of the region and how that geology affects the transmission of seismic signals. This project is discussed in detail in the Research Highlights section of this report.